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RESEARCH PAPER

Hedonic Price Analysis of Teak Logs

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Abstract Implicit economic values of physical attributes of teak logs (girth, length, straightness and soundness) were estimated using hedonic regression. The influence of spatial and temporal variations on teak wood prices was also estimated. The auction prices of teak wood at various Timber Sales Depots of the Forest Department of Kerala State in India during the period 2006–2010 were used for the study. Traders ascribed over 80 % of variation in teak wood prices to girth, straightness and soundness of logs. A reduction in age at felling of teak plantations in forest areas is proposed. The study also underlines the need to continue tree improvement programs and silvicultural operations for the production of high quality teak wood and thereby increase the profitability of teak plantations.

Keywords Timber quality · Hedonic regression · Teak plantation · Home garden

Introduction

Hedonic price analysis is useful to obtain the economic value of various characteristics of a good (Hulten 2003). The hedonic technique estimates hedonic values which are defined as the implicit prices of traits and are revealed by observed prices of differentiated products and the specific amounts of traits associated with them (Lancaster 1966; Rosen 1974). There are two basic approaches to understand the characteristic price. Lancaster (1966) proposed a theory of consumer utility based on characteristics rather than on goods. Rosen (1974) related the hedonic function to the supply and demand for individual characteristics, that is, to the demand curves of consumers with heterogeneous tastes for differing combinations of characteristics in each variety, and to the corresponding supply functions for each

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characteristic. Further discussion on these two approaches is available in Triplett (1983), Epple (1987), Feenstra (1995) and Diewert (2003).

The relation between price of a particular good and its attributes can be expressed as $p = f(X)$, where p is the price of the good and X is the good's vector of characteristics. The value of the partial derivative of the equation with respect to each of the element of the characteristic vector is the marginal implicit price of (or marginal willingness to pay for) a one unit change in the corresponding characteristic variable (Hanley and Spash 1993; Garrod and Wills 1999).

The rapid quality changes in the number of commodities such as automobiles and computers have led to the development of quality-adjusted consumer price indices using a hedonic price approach (Griliches 1961; Berndt and Rappaport 2001). Hedonic price equations were developed relating wine prices with the characteristics appearing on the label of the wine bottle and sensory and other characteristics of wine (Nerlove 1995; Combris et al. 1997). The hedonic price analysis was used to determine the influence of attributes and factors of prices of livestock including sheep and goats (Akinieye et al. 2005) and indigenous chickens (Bett et al. 2011).

Alzamora and Apiolaza (2010) recognized that forest hedonic price models were mostly concerned with the impact value of environmental amenities. As far as the timber sector is concerned, hedonic studies are scarce. Brannman et al. (1981) used hedonic methods to develop quality-adjusted price indices for Douglas-Fir timber. Bloomberg et al. (2002) explained the regional differences in the price of radiata pine in New Zealand through log attributes using a hedonic price model. Alzamora and Apiolaza (2010) applied hedonic models to value wood attributes at the log and tree level for appearance-grade lumber of *Pinus radiata* in Chile.

Among all timbers, teak is considered to be a premium and high value timber worldwide due to its strength, durability, appearance, colour (mostly golden yellow or brown) and grain (Bhat 1998; Thulasidas et al. 2006). However, an empirical analysis on economic potential of traits such as girth, length, straightness and soundness of teak logs has not been attempted. The objective of this study was to estimate the implicit economic value of the characteristics of teak wood by estimating a hedonic price model.

Study Site and Data Used

The study was conducted in the state of Kerala, a narrow strip of land located in the south-west corner of the Indian Peninsula between north latitude 8°18′ and 12°48′ and east longitude 74°52′ and 77°22′. It encompasses an area of 38,863 km^2. The state has a forest area of 11,309 km^2, of which about 13 % is plantation forest. Teak is the major species contributing about 53 % to the total area under forest plantations (KFD 2009). In India, forests are managed by the Forest Departments of the State Governments under the guidelines of the Ministry of Environment and Forests, Government of India. The Kerala Forest Department is responsible for managing the forests including forest plantations in that State. The timber is felled only from forest plantations, timber felling from natural forests being banned.

Table 1 Criteria for major classification of teak wood

Straightness and soundness		Girth		Length	
Grade	Criteria	Girth class	Middle girth (cm)[a]	Length class	Length (m)
A	Logs straight and sound without any defects	Export	185 and above	SL (short log)	Above 1 and below 2.5
B	Fairly straight and sound logs	I	150–184	LL (lengthy log)	2.5–7.3
C	Defective and crooked logs	II	100–149	LLL (long lengthy log)	Above 7.3
D	Highly defective and crooked logs	III	75–99		
		IV	60–74		

[a] Middle log girth (under bark)

Timber felled from forest plantations is deposited for sale in 30 Sales Depots across 6 Forest Sales Divisions. The timber supplied to each Forest Depot is mostly from neighbouring forest plantations. The major species sold through Sales Depots is teak. Round timber of teak is traditionally classified into 45 classes based on mid-girth, length and straightness and soundness of logs (Table 1) (KFD 2011). Though poles and billets were also graded, they are excluded here. Prior to sale, timber logs are arranged into lots based on quality attributes of the individual logs. A lot may contain one or more logs but the volume does not exceed 5 m^3. Sale is by both tender and auction. The sales are awarded to the highest bidder. Timber grading and sale are carried out by the Manager of the Timber Depot under the supervision of the Officer of the Timber Sales Division.

Price data were collected from Sales Depots by contacting them both in person and by mail at 6 monthly intervals, and were compiled for the analysis. The data were aggregated by auction date for each year during the period 2006–2010 for developing the hedonic model. The number of auctions covered during the period for the analysis was 421 which gave 4,518 data points over various quality attributes over a sale quantity of 60,811 m^3. The weighted average prices of teak[1] (Rs./m^3) were calculated considering quantity of timber sold as weights. The annual volatility of teak prices was expressed as the percentage of standard deviation to average current teak wood prices.

Development of Hedonic Price Model

Teak is priced high due to its number of physical and wood quality attributes. The physical attributes include girth, length, straightness and soundness of logs. The wood properties include strength, appearance, colour, texture, grain, durability and aesthetic value. Traders also associate value with the age of the teak and location where it was grown because of quality differences. Because teak sold in government timber depots is usually felled at the age of 55–60 years, age was not considered while

[1] Indian rupees per cubic metre. Rs. 44.70 = $US 1, as at January 2, 2006.

grading the timber. The differences in colour and grain were also not considered while grading. Though more distinct classification was possible with respect to physical properties of teak wood based on the quantification of attributes such as number of bends, holes, cracks, knots, buttresses and splits, as per Indian Standard Grading Rules for Teak logs (ISI 1969), these properties were not differentiated. The grading rules followed by the timber depots were as per the guidelines of the Kerala Forests and Wildlife Department (KFD 2011) based on girth, length and straightness and soundness of logs (Table 1). The straightness and soundness of logs was assessed by visual inspection of attributes without actually being quantified. In this study, five variables were considered for developing the hedonic model.

The coding scheme followed for the purpose of analysis is:

1. Girth (mid-girth of logs, under bark), coded as 1–5 for the girth class IV to export,
2. Straightness and soundness, coded as 1–4 for the class D to A,
3. Length, coded as 1–3 for length class SL to LLL,
4. Timber Sales Division, as a dummy variable to consider spatial variation. Its value is 1 if the particular Timber Sales Division is present else its value is 0 (5 dummy variables were created for 6 Timber Sales Divisions studied).
5. Quarter, as a dummy variable to take into account seasonal (quarter to quarter) variation within a calendar year. Its value is 1 for all the observations in the particular quarter else its value is 0 (3 dummy variables were created for 4 quarters).

Selection of the Best Functional Form of Hedonic Model

Economic theory places few restrictions on the form of the hedonic price function. In developing hedonic regression solutions, four functional forms have been employed in the past, viz. simple linear, exponential, power function or double log, and logarithmic models (Brachinger 2002). All the non-linear functional forms were converted into linear form and solutions were obtained using the ordinary least squares multiple regression analysis procedure in SPSS 14.0 software.

Researchers mostly use goodness of fit criterion to choose the appropriate form of the hedonic function (Cropper et al. 1988). In this study, the data were subjected to regression analysis of the above functional forms and the best functional form was chosen based on adjusted R^2 value and its significance was tested by F-test. The simple linear model was found to have the highest R^2 value (80–85 %) for all the years. The following is the functional form of the hedonic regression equation.

$$\begin{aligned}\text{Price} = \text{Constant} &+ b_1\,\text{Straightness and soundness} + b_2\,\text{Girth} + b_3\,\text{Length} + \\ & b_4C_1 + b_5C_2 + b_6C_3 + b_7D_1 + b_8D_2 + b_9D_3 + b_{10}D_4 + b_{11}D_5 + \text{Error}\end{aligned}$$

where the b_is ($i = 1,2,\ldots 8$) are regression coefficients (partial derivatives). C_1 to C_3 are the dummy variables for quarter. C_1-fourth quarter; C_2-third quarter; C_3-second quarter. D_1 to D_5 are the dummy variables for Timber Sales Division (spatial variable). D_1-Palakkad; D_2-Kottayam; D_3-Perumbavoor; D_4-Thiruvananthapuram; D_5-Kozhikode.

With regard to spatial effect in the above equation, non-significant dummy variables representing the Timber Sales Divisions ($P > 0.10$) were excluded from the regression equation.

Outliers of Teak Prices

The variation in teak prices is usually high. Sometimes, there are extreme observations or outliers that exist in price data. The data with large residuals (outliers) and high leverage may distort the outcome and accuracy of estimates of regression parameters. Cook's distance (D_i) is commonly used to estimate the influence of a data point when carrying out least squares regression analysis (Montgomery and Peck 1982). It measures the effect of deleting an individual observation. The data points with a large Cook's distance are considered to merit closer examination in the analysis. The Cook's statistic is

$$D_i = \frac{\sum_{j=1}^{n} \left(\hat{Y}_j - \hat{Y}_{j(i)}\right)^{.2}}{q\,MSE}$$

The following is an algebraically equivalent expression

$$D_i = \frac{e_i^2}{qMSE}\left[\frac{h_{ii}}{(1-h_{ii})^2}\right].$$

In the above equations:

$\hat{Y}_j$ is the predicted teak price value from the full regression model for observation j;
$\hat{Y}_{j(i)}$ is the predicted teak price value for observation j from a refitted hedonic regression model in which observation i has been omitted;
h_{ii} is the ith diagonal element of the hat matrix $X\left(X^T X\right)^{-1} X^T$ (where X is the matrix of values of the good's vector of characteristics);
e_i is the residual (i.e. the difference between the observed and predicted teak prices);
MSE is the mean square error of the regression model; and
q is the number of fitted parameters in the regression model.

In order to calculate the Cook's distances, least square regression analysis was run with teak prices as dependent variable and girth, length and straightness and soundness of logs as independent variables. The observations for which

$$D_i \geq \frac{4}{n-(q+1)}$$

were considered as outliers and omitted for the analysis. The percentage of outliers to the total observations ranged from 5.7 in 2006 to 8.0 in 2007.

Model Diagnostics

Following Montgomery and Peck (1982), a number of diagnostic procedures were applied to satisfy the assumptions of least square regression analysis. The data without extreme observations satisfied the assumption of normality as examined through normal probability plot of standardized residuals. There was no evidence of muticollinearity (correlation among the attribute variables) as determined by the value of the Variance Inflation Factor (VIF < 5.0). The presence of heteroscedasticity (heterogeneity of variances at different levels of attribute variables) was examined by a scatter plot of standardized residuals against standardized predictive values and its significance was tested by White's test and the Breusch–Pagen test. Although there existed slight heteroscedasticity ($p < 0.05$), an attempt to overcome this by developing alternative solutions did not yield a higher adjusted R^2. In this study, the price data of teak wood is unbalanced for quantity sold at various combinations of predictors. In such situation, weighted regression analysis is usually attempted. Since no quantity was sold or very few observations were available in many combinations of teak wood classes, weighted regression analysis would not have been meaningful. In particular, regression analysis with weights including quantity sold and relative quantity sold, and with weights inversely proportional to variance at each combination of predictor variables, did not yield satisfactory results in hedonic price analysis.

Results

About 90 % of the teak sold belonged to six major classes (Table 2). The average price varied widely (Table 3). The median percentage volatility varied from 14 in 2010 to 19 in 2007 and 2009. However, the percentage volatility was higher in straightness and soundness class *D* across all the girth and length classes. The increase in average current prices of teak logs from 2006 to 2007 was about 32 %. This was due to short supply of teak wood from forest plantations coupled with high timber demand from the unprecedented growth in house construction and furniture making. Only a marginal increase was seen from 2008 onwards, perhaps due to the impact of the global financial crisis.

Hedonic Price Model

Table 4 shows the results of the hedonic regression analysis. The coefficient of determination (R^2) is 80 % and above, meaning that the model developed explained over 80 % of the variation in teak wood prices. The standard regression coefficients and the estimated percentage of variation in teak wood prices explained by each of the independent variables reveal that girth is the most important attribute, explaining 42 % of the variation in 2007 to 54 % in 2010 (Fig. 1). This was followed by straightness and soundness of logs which explained 25–31 %. The length of teak logs is estimated to explain about 4 % of the variation in teak prices. The spatial and

Table 2 Quantity sold across major classes of teak wood (m^3)

Girth	Straightness and soundness	Length	Years 2006	2007	2008	2009	2010
II	B	LL	2,090.33 (54)	1,443.7 (50)	3,005.36 (89)	2,174.12 (88)	2,799.69 (98)
II	C	LL	1,724.39 (64)	1,146.3 (53)	1,471.92 (90)	1,589.33 (88)	2,911.04 (111)
III	B	LL	3,010.57 (54)	1,751.98 (46)	2,736.25 (87)	2,681.47 (87)	2,733.15 (102)
III	C	LL	2,403.53 (67)	1,450.97 (51)	2,311.5 (91)	2,543.86 (87)	2,991.17 (105)
IV	B	LL	1,342.12 (44)	753.01 (44)	974.94 (69)	1,106.21 (83)	681.94 (86)
IV	C	LL	1,503.43 (62)	927.02 (51)	1,386.16 (84)	1,405.22 (84)	1,145.78 (97)
Total			13,213.76 (748)	8,043.03 (610)	12,749.84 (1,009)	12,345.55 (1,010)	14,458.85 (1,141)

[a] Numbers in parenthesis are numbers of auctions covered

Table 3 Average price and percentage volatility of major classes of teak wood prices (Rs/m^3)

Girth	Straightness and soundness	Length	2006	2007	2008	2009	2010
II	B	LL	51,679 (14)	73,412 (17)	79,086 (18)	78,070 (13)	79,044 (13)
II	C	LL	35,435 (19)	47,469 (25)	51,965 (22)	54,551 (22)	56,056 (16)
III	B	LL	36,614 (12)	52,333 (17)	51,115 (22)	54,733 (12)	55,978 (17)
III	C	LL	26,467 (16)	33,179 (18)	32,590 (21)	36,761 (19)	39,399 (15)
IV	B	LL	27,005 (13)	33,576 (16)	34,716 (19)	36,672 (18)	41,145 (14)
IV	C	LL	18,983 (17)	24,154 (19)	23,215 (23)	26,601 (21)	30,153 (17)

[a] Figures in the parenthesis indicate percentage volatility

inter-quarter effects are significant only in some years and contributed only about 2 % to the variation in teak wood prices.

The hedonic regression analysis reveals that the economic value (average rate of change in teak prices) that can be attributed to a change in the level of straightness and soundness (say from D to C or C to B or B to A) was Rs. 10, 663/m^3 in 2006, rising to 19,662/m^3 in 2008. Similarly, the economic value attributed to a change in the level of grading based on girth was Rs. 10,315/m^3 in 2006, rising to Rs. 18,535/m^3 in 2008. The economic value of length characteristic was only about Rs. 5,863/m^3 in 2006, increasing to Rs. 9,530/m^3 in 2008. The analysis indicates that the teak price increased significantly over the quarters in 2006 and 2009. The coefficients of the dummy regressors indicated that the Palakkad and Kottayam Timber Sales Divisions fetched higher prices than the other Timber Sales Divisions in the years 2008 and 2010.

Discussion

The hedonic price analysis reveals that the timber valuation by traders is mainly based on girth, straightness and soundness of logs. The economic value of attributes appears to vary between years depending on the demand and supply levels of the characteristics of teak wood. The hedonic analysis could not be performed for home-garden teak wood because only small quantities were traded through middlemen and reliable price data were difficult to collect.

Teak from Palakkad Timber Sales Division fetched higher prices than that from other Divisions because most of the timber arrived for auction at the Timber Depots of this Division were from Nilambur forest areas, which is known for its high quality teak wood (Balasundaran 2010). In order to estimate the economic values of attributes such as grain, colour and appearance and to relate with variation in supply and demand of teak wood it is necessary to undertake studies covering teak wood supply from forest plantations, home gardens, farm land and imports, and demand for various end uses. The studies should cover both organized and unorganized timber markets across various states.

Table 4 Parameter estimates of the various attributes of teak wood included in the hedonic regression model

Attribute	Parameter estimates	Years				
		2006	2007	2008	2009	2010
Constan*t*	$\widehat{b_0}$	−27,698.69***	−45,910.87***	−62,481.06***	−45,481.71***	−46,357.84***
	SE $(\widehat{b_0})$	1,452.60	2,439.82	2,307.41	1,664.88	1,942.61
Straightness and soundness	$\widehat{b_1}$	10,663.72***	17,372.65***	19,661.72***	16,341.02***	18,357.43***
	SE $(\widehat{b_1})$	375.29	703.89	577.42	450.01	423.77
	$\widehat{\beta_1}$	0.46	0.49	0.47	0.48	0.51
Girth	$\widehat{b_2}$	10,315.48***	15,109.87***	18,534.82***	17,131.60***	16,672.26***
	SE $(\widehat{b_2})$	233.32	433.75	358.86	310.42	264.40
	$\widehat{\beta_2}$	0.69	0.65	0.69	0.70	0.74
Length	$\widehat{b_3}$	5,863.47***	8,807.52***	9,530.05***	8,648.01z***	8,702.86***
	SE $(\widehat{b_3})$	422.13	794.75	660.54	547.38	584.90
	$\widehat{\beta_3}$	0.22	0.22	0.20	0.21	0.18
C_1	$\widehat{b_4}$	1,428.04*	358.73	472.30	1,245.47	−3,955.88***
	SE $(\widehat{b_4})$	719.40	1,243.75	1,122.42	859.60	1,017.99
	$\widehat{\beta_4}$	0.04	0.01	0.01	0.02	−0.07
C_2	$\widehat{b_5}$	2,750.35***	1,864.93	385.36	3,831.68***	−1,879.27
	SE $(\widehat{b_5})$	735.99	1,305.62	1,082.44	843.65	1,029.02
	$\widehat{\beta_5}$	0.08	0.04	0.01	0.07	−0.03
C_3	$\widehat{b_6}$	3,712.91***	2,329.61	−1,058.90	5,020.22***	−1,118.41
	SE $(\widehat{b_6})$	801.69	1,447.92	1,084.52	953.04	1,054.11
	$\widehat{\beta_6}$	0.09	0.04	−0.02	0.08	−0.02

Table 4 continued

Attribute	Parameter estimates	Years				
		2006	2007	2008	2009	2010
D_1	$\widehat{b_7}$	*NS*	*NS*	5,864.08***	−943.84	3,126.80*
	SE ($\widehat{b_7}$)	*NS*	*NS*	1,122.04	828.47	1,304.93
	$\widehat{\beta_7}$	*NS*	*NS*	0.10	−0.02	0.05
D_2	$\widehat{b_8}$	716.88	−4,695.00	4,933.72	*NS*	4,359.37***
	SE ($\widehat{b_8}$)	826.34	2,433.39	1,466.11	*NS*	947.90
	$\widehat{\beta_8}$	0.01	−0.04	0.05	*NS*	0.07
D_3	$\widehat{b_9}$	−3,712.45***	−3,650.33***	−832.03	−5,444.35***	−2,223.43*
	SE ($\widehat{b_9}$)	700.92	1,092.36	1,221.59	954.52	946.46
	$\widehat{\beta_9}$	−0.10	−0.07	−0.01	−0.08	−0.04
D_4	$\widehat{b_{10}}$	−357.47	−1,855.57	1,644.42	−1,887.64	−1,464.19
	SE ($\widehat{b_{10}}$)	1,835.72	2,861.74	2,886.55	2,207.07	1,022.03
	$\widehat{\beta_{10}}$	0.00	−0.01	0.01	−0.01	−0.02
D_5	$\widehat{b}_{11}$	−2,665.80***	−7,151.26***	−112.82	−3,894.09***	1,670.61
	SE ($\widehat{b}_{11}$)	637.55	1,213.13	1,270.76	851.87	962.82
	$\widehat{\beta_{11}}$	−0.08	−0.13	0.00	−0.07	0.03
Goodness of fit statistics	Adjusted R^2	0.82	0.80	0.82	0.84	0.85

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

$\widehat{\beta}$s are estimates of standardized regression coefficients

NS means attributes having probability of F-value greater than 0.10 (do not contribute to the model's explanatory power) and excluded from the regression equation

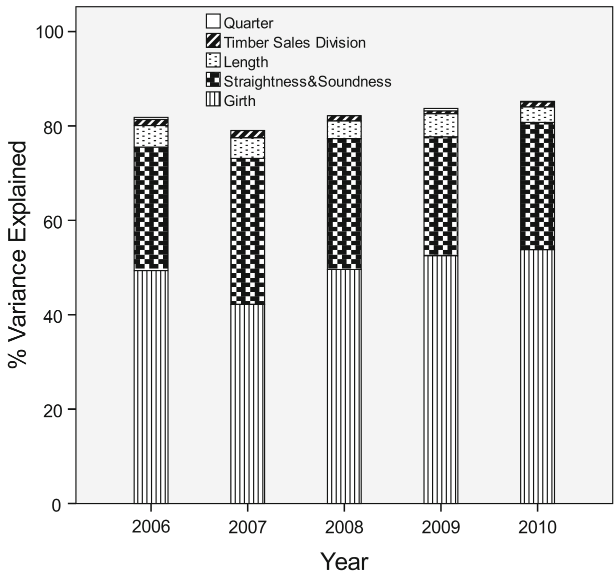

Fig. 1 Percentage variance explained in prices of teak wood by various quality characteristics

Conclusion

Teak can be expected to be in great demand for its typical attributes. The study has estimated huge economic values associated with girth, straightness and soundness of logs to about 80 % of the variation in teak wood prices. The maximum annual increment (MAI) in volume of teak in forest plantations, mostly determined by girth, is stabilized at a plantation age of about 45 years (FRI 1970). The MAI and the economic potential of the logs suggest that it is possible to bring down the felling age at about 45 years from the present practice of 55–60 years for earlier economic benefits. The growth models developed by Jayaraman and Rugmini (2008) and studies by Palanisamy et al. (2010) also indicate that the felling age of teak could be brought down to below 50 years.

The study suggests that tree breeders should consider size and straightness and soundness of logs as vital selection indices to define breeding objectives. The plantation managers should give greater emphasis on site selection, quality planting material, and timely silvicultural practices (thinning, weeding) to produce high quality teak wood. Though the best teak clones are developed their field evaluation has been lacking for large-scale planting. Teak growers across farms and home gardens may also be made aware of the economic values of teak attributes. Such activities would make teak growing a more attractive business enterprise given the short supply of teak wood.

Policy Implications

The Forest Policy of the Indian States underlines the need to promote productivity of forest plantations to meet the timber needs of future generations. The quality of teak plantations has been declining over time, especially teak plantations which have been through successive rotations (FAO 2001). Therefore, an explicit statement on developing high quality plantations in policy documents would increase quality consciousness among foresters and tree growers. The promotion of superior teak provenances and clones can be emphasized in this regard.

In India, the forest plantations are mostly managed under the Working Plans of the various Forest Divisions prepared at the interval of every 10 years. The plans are prepared following traditional age-old guidelines. Based on the latest findings there could be changes in the age at felling of teak plantations on an experimental basis and expanded later based on an economic evaluation.

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